15.1 Printable Electronics for Polymer RFID Applications

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Organic electronics create new opportunities of inexpensive RFID tag production techniques such as printing processes, which are only possible with soluble materials like polymers. Concepts for the production of fast integrated circuits based on p-type organic transistors have been demonstrated [1] using soluble polymers for active layer and insulating layer. A number of organic RFID-related building blocks and components have recently been published [2,4-7]. This paper presents a passive organic transponder that uses a base-carrier frequency of 13.56MHz, designed for item-level tagging. The transponder prototype carries no ID and is mainly designed as a feasibility study. In the near future, data storage and implementation of a communication protocol will be pursued. Due to low charge carrier mobilities of $\mu \approx 0.02 cm^2/Vs$ the internal clock signal of the polymer-based transponder cannot be generated from the carrier signal as is done in many silicon-based RFID applications. The developed organic devices are air stable, even without encapsulation and all measurements were taken under ambient conditions.

The manufacturing process of the transponder prototype is completely compatible with a printing process for mass production. The minimum structure size for printing is 20µm. Regarding the prototype transponder, all electrodes are patterned with a lithography mask using standard photolithography. The minimum structure size using this process is 5µm. The substrate for all devices is a flexible polyester film. Up to six different layers for Source/Drain-electrodes, polymer semiconductor for transistors, insulator for transistors, semiconductor for diodes, insulator for capacitors and gate-electrodes are applied. The field effect transistors (FET) are based on a top gate concept with source and drain consisting of a 40nm gold layer. The semiconducting layer of approximately 50nm thickness is applied by a spincoating process using a p-type soluble polymer poly 3-hexylthiophene (P3HT). A 300nm thick soluble organic copolymer blend is spin-coated on as insulating layer [1]. Rectifier diodes are developed based on soluble poly 3-alcylthiophene (P3AT) as p-type semiconductor whereas anode and cathode are realized as metal contacts [2]. The capacitors are made with a proprietary blend of soluble insulating polymer between two metal electrodes. [1]. Copper was chosen in order to get high quality loop antennas that were structured by common etching techniques.

Figure 15.1.1 shows the system overview of the reader that drives an organic transponder at a certain distance d. On the reader side a serial resonance circuit of reader loop antenna and a tuning capacitor is supplied by a signal generator that produces a 13.56MHz sine voltage with amplitude $U_{g,p}$. The reader antenna has five turns of 10cm diameter and is matched to a 50Ω impedance.

The transponder loop antenna in conjunction with the input capacitance of the organic rectifier represent a parallel resonance circuit that is tuned to the carrier frequency of 13.56MHz. The transponder antenna has five ampere-turns of 5cm diameter and a quality of $Q \approx 200$. The overall area of the transponder circuit is about $4cm^2$. The reader and transponder antenna represent an inductively coupled system where energy flows in the form of an alternating magnetic field from the reader to the transponder. The quality of the resonance circuit is constrained by losses due to the antennas, the capacitors, the input resistance of the voltage source U_g and the input resistance of the organic rectifier.

The rectifier is based on an organic diode with an active organic semiconductor layer sandwiched in between two metal electrodes. The rectifying behaviour of the diode is caused by the Schottky effect at the cathode-semiconductor transition [2] whereas the anode material forms an ohmic contact with the semiconductor. A typical characteristic IV curve of an organic diode with threshold voltage U_{th}=0.7V is shown in Fig. 15.1.2. A dc voltage U_R, which depends on the input ac voltage U_2, is produced at the rectifier's output capacitance. This capacitance supplies a time varying load - in our case a digital modulation circuit. Therefore, the supply voltage U_R depends on the load, e.g. the power consumption of the digital modulation circuit. All transistors in the modulation circuit use p-type semiconducting polymer. Figure 15.1.3 shows the schematic and measured voltage transfer characteristics of a basic inverter as well as the drain current versus drain source voltage characteristics of a transistor [3].

The ring oscillator, consisting of 15 inverters in series, generates a clock signal that is amplified by two inverter stages. The amplified signal drives a transistor of high W/L ratio to modulate the overall power consumption of the circuit, which is a wanted effect to realize communication. The schematic of the modulation circuit is depicted in Fig. 15.1.4. As the supply voltage U_R increases to an operating value $V_{dd,min}$=-6V the ring oscillator starts oscillating with a frequency $f_{cycle}(V_{dd})$ that depends on its supply voltage. The modulated power consumption of chip and modulation transistor is expected to be observed as load modulation at the output voltage U_R of the rectifier and at the transponder antenna voltage U_2. As the input resistance of the rectifier depends on its load, the quality of the transponder resonance circuit is modulated as well. This modulation is transferred by inductive coupling to the reader antenna and can be detected by envelope demodulation $U_{1,d}$ of the antenna voltage U_1.

A generator voltage amplitude of $U_{g,p}$=8V was applied to the reader by a carrier frequency of f=13.56MHz. The organic transponder was measured at various distances from the reader controlled by an automatic positioning test system. Figure 15.1.5 shows the rectified dc supply voltage U_R of the modulation circuit measured for d=10mm,...,100mm. U_R has an absolute maximum at 25mm and is decreasing with d as the magnetic field strength does. At smaller distances U_R decreases as reader and tag resonance frequencies are detuned due to stronger inductive coupling. The modulation circuit started oscillating at U_R<-6V. Therefore, the range of operability can be determined by the U_R-d curve in Fig. 15.1.5 for distances from d=10mm to d=47.5mm. To measure a representative modulation signal the transponder was positioned at a distance of d=30mm to the reader. The modulation on transponder side and on reader side is shown in Fig. 15.1.6 and the oscillation frequency can be determined as f_{cycle}=120Hz.

In summary, a proof of concept passive organic transponder for a carrier frequency of 13.56MHz is presented. All involved layers consist of printable polymers except the electrodes. The operational range of the transponder is d=0,...,4.75cm while the clock frequency is 120Hz. Due to the use of inductive coupling, the operating range is limited by the law of physics to $d_{max} \leq c/2\pi f$=3.5m for f=13.56MHz, independent of the reader antenna size. To maximize the H field at a certain distance d, the radius of the reader antenna r can be chosen to be $r \cong \sqrt{2} \cdot d$.

References:
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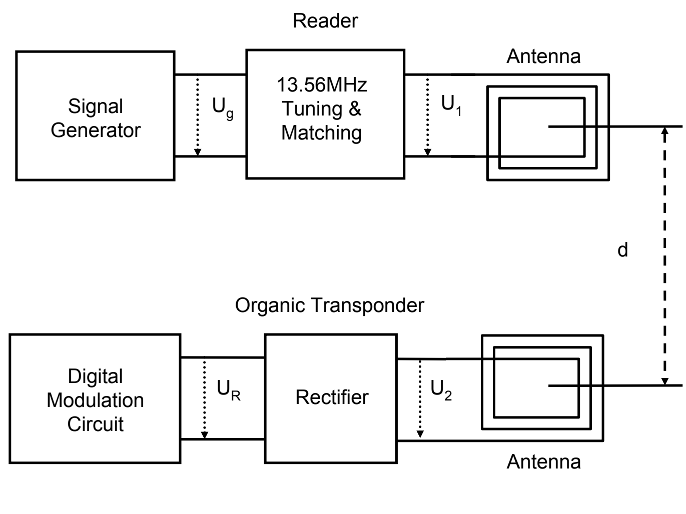

Figure 15.1.1: System overview.

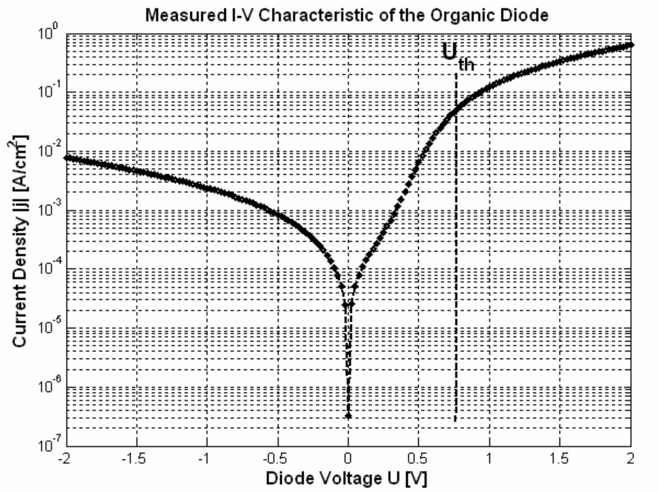

Figure 15.1.2: Organic diode.

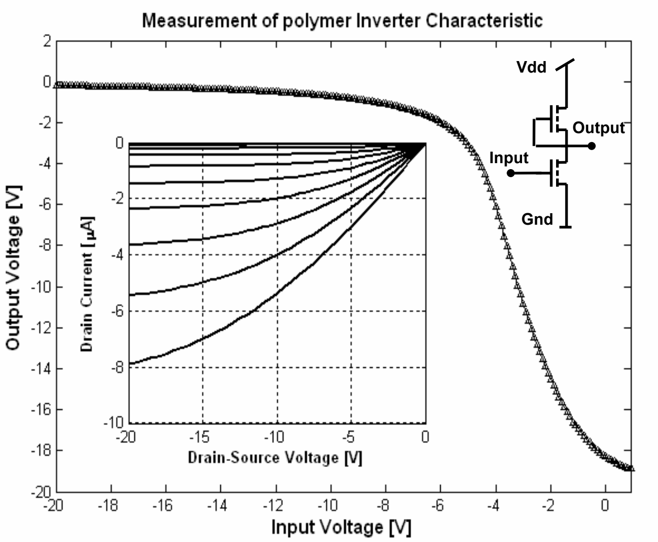

Figure 15.1.3: Organic p-type inverter.

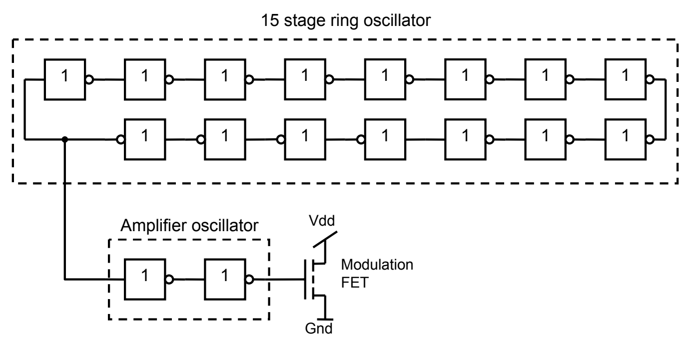

Figure 15.1.4: Organic digital modulation circuit.

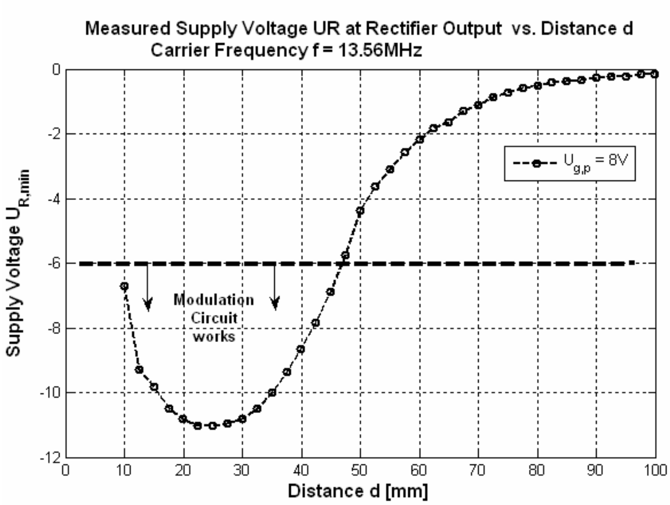

Figure 15.1.5: Chip supply voltage versus distance.

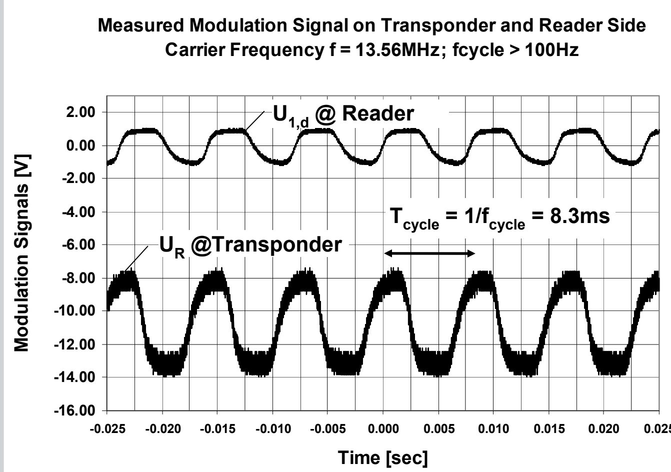

Figure 15.1.6: Modulation on transponder side and on reader side.